College of Arts and Sciences
Honors Program
UNIVERSITY OF COLORADO **BOULDER**

Spring 2018
Registration to Graduate with Honors

Student Information (Please print clearly.)

First and last name:	Student ID:
Omkar H. Ramachandran	105963120
CU Boulder email address:	Major you are writing a thesis in:
omkar.ramachandran@colorado.edu	Physics

Honors Information and Requirements (Please initial all applicable boxes.)

OHR	**All students:** I have attached a prospectus, bibliography, and timeline of my project.
OHR	**Departmental Honors students:** I am writing a thesis in my major and not in a minor.
	General Honors Students: I have attached my General Honors Eligibility Worksheet to this form.
	Concurrent Bachelor's/Masters Degree students: I am an undergraduate student who will have earned under 130 credits by my thesis defense.

Thesis Committee: Thesis committees require at least three members of the CU Boulder faculty. To be eligible to serve on a thesis committee one must be a regular full-time faculty member or a multi-year contract instructor involved in an instructional program at the University of Colorado Boulder. In terms of rank, this means Professor, Associate Professor, Assistant Professor, Senior Instructor, or Instructor.

Faculty Name (please print)	Department	Teaching Rank
Thesis advisor: Dr. Axel Brandenburg	APS	Professor
Honors Council representative: DR. JOHN CUMALAT	PHYSICS	PROFESSOR
Third member/outside reader: Dr. Phil Armitage	APS	Professor
Additional member (optional): DR. DMITRI UZDENSKY	PHYSICS	ASSOC. PROFESSOR

Signatures

Thesis Advisor: I have discussed the project proposal with the student and agree to provide the necessary help and direction for the project.

Signature [signature]

Honors Council Representative: I have met with the student and give my department's approval for them to pursue Latin honors. I agree to serve on the thesis defense committee.

Signature John P. Cumalat

Student: I have consulted with my department and/or the Honors Program and have completed/am completing the requirements that they have established. If I choose to defer my project to another semester or withdraw from the thesis process, I will inform the Honors Program Office.

Signature Omkar H. Ramachandran

Name: Omkar H. Ramachandran
Research Advisor: Dr. Axel Brandenburg
Research Field: Cosmology
Expected Semester of Graduation: Spring 2018

Understanding the helicity of Extragalactic Magnetic Fields through analysis of Photon arrival directions

Abstract

A recent study by Tashiro et al. (2014) [1] have suggested a mechanism through which the helicity of the primordial magnetic field could be estimated by analyzing the arrival directions of TeV photons generated from cascade emission around blazars. This can be used to construct a pseudoscalar Q which, in turn, can be related to the helicity of the magnetic field. While the study finds a negative values of Q in certain energy ranges, a more extensive analysis is needed to explain anomalies – such as the apparent hemispheric dependence of the measured pseudoscalar – and, more generally, to verify the overall claim about an underlying helical magnetic field. The aim of this project will be to use more recent data available from the Fermi Large Area telescope (LAT) to explore this claim, and to understand the dependence of the measured helicity on the local spatial configuration of the arriving photons.

Prospectus

Recent work by Kahniashvili and Vachaspati (2006)[3] has demonstrated that arrival momenta of cosmic rays is sensitive to the helicity of the intervening magnetic field between the source and detector. Given this result, it is possible to infer this helicity if one is provided the spatial distribution of incoming photons of different energies from a singular source by measuring the following statistic[2]:

$$Q = \langle (n(E_1) \times n(E_2)) . n(E_3) \rangle$$

where $n(E_i)$ represents the unit vector of an arriving photon with energy E_i on the sky. In the Tashiro et al. (2014) study[1], photon data from Pass 7 of the Fermi LAT was analyzed to show that the measured value of Q was negative for different combinations of photons in the 10 to 60 GeV range, suggesting – assuming the spatial distribution was caused by a primordial magnetic field – a field strength of $10^{-14}G$[1]. This result agrees with work done by Dolag et al. (2010)[6], which implies extragalactic magnetic fields stronger than $O\left(10^{-16} - 10^{-15}\right) G$. While this is a significant claim, some of the anomalies in the study have to be verified, such as the apparent hemispheric dependence of Q. In addition, the study as a whole has to be extended to include a larger spread of photon arrival directions and energy range combinations.

The aim of this project is to perform the extensions described above. Specifically, I will attempt to use the more recent Pass 8 data of Fermi LAT to explore the variation of Q with a larger spread of energies, hemispheric dependence (which would potentially indicate a dominant galactic magnetic field as opposed to an extragalactic one) and the overall effect of changes in the local spatial configuration of the arriving photons.

References

[1] ”Search for CP violating signature of intergalactic magnetic helicity in the gamma-ray sky”, H. Tashiro et al., MNRASL **445** L41-L45 (2014).

[2] “Cosmological magnetic field correlators from blazar induced cascade”, H. Tashiro and T. Vachaspati, Phys. Rev. D **87** 123527 (2013).

[3] ”On the detection of Magnetic Helicity”, T. Kahniashvili and T. Vachaspati, Phys. Rev. D **73** 063507 (2006)

[4] ”Relaxation of Blazar Induced Pair Beams in Cosmic Voids”, F. Miniati and A. Elyiv, ApJ **770** 54 (2013)

[5] ”Plasma Effects on Fast Pair Beams in Cosmic Voids”, R. Schlickeiser, D. Ibscher and M. Supsar, ApJ **758** 102 (2012)

[6] ”Lower Limit on the Strength and Filling Factor of Extragalactic Magnetic Fields”, K. Dolag, M. Kachelriess, S. Ostapchenko and R. Tomas, ApJ **727** L4 (2011)

[7] ”Sensitivity of γ-ray telescopes for detection of magnetic fields in intergalactic medium”, A. Neronov and D. V. Semikoz, Phys. Rev. D **80** 12301 (2009)

[8] ”Cosmic microwave background and helical magnetic fields: The tensor mode”, C. Caprini, R. Durrer and T. Kahniashvili, Phys. Rev. D **69** 036006 (2004)

Timeline

- **December 2017**
  - Week of 11: Wrote code that computes the Q sum for one pixel in space for a single week of Fermi-LAT data
  - December 18 to 22: Came up with technique to speed up the triple product sum computation
  - to Jan 6 (Winter break): Extended code to create a map in (θ, ϕ) that computes Q for each pixel defined by $(\theta[i] + d\theta, \phi[i] + d\phi)$ for some $d\theta$, $d\phi$
- **January 2018**
  - Week of 8: Used 40 weeks of LAT data (70857 photons and 1.3×10^{12} combinations) and studied overall dependence on pixel size and temporal variation in $Q(\theta, \phi)$
  - Week of 15:
    * Rewrote core loop to exactly replicate Tashiro et al.'s results for 40 weeks of LAT Pass 8 data. Results seem to indicate a strong dependence on hemispherical location ($\langle Q_{GLAT<0} \rangle < 0$ and $\langle Q_{GLAT>0} \rangle > 0$ with $\langle Q_{total} \rangle < 0$)
    * Jan 19, 2018: Complete and submit honors paperwork latest by Friday afternoon
  - 01/22 to 02/05:

    * Scrub data to remove known High Energy (1FHL) sources from the current analyzer.
    * Extend analysis to include 100 weeks of data.
    * Rewrite the pixel-generating code to use Tashiro et al.'s method within a given pixel - with pixel boundaries only used to choose photons in the E_3 bin
    * Initially use a random filter and later match photons in the north and south by their time stamp to have an equal number of points in the northern and southern hemispheres and repeat the analysis. This will potentially show, beyond a reasonable doubt, whether there is global hemispheric dependence.

- **February 2018**
  - 02/05 to 02/19
    * Complete background and introduction of thesis draft by **Friday 02/16**.
    * Extend analysis to use the entire Pass 8 data set (~500 weeks of data by this point)
    * Depending on the result, analyze the dependence of triple product triangles by characterizing the shape through area and the intermediate angle (this might require running GPU based simulations on Summit – I have personal time on the cluster that I can use towards this)
- **March 2018:**
  - Write up first round of results for the thesis draft and complete analysis
  - Depending on the result of the project by the end of February, explore more subtle effects of the local spatial configuration
- **Week of 03/15/2017**: Complete major research activities
- **March 22, 2017**: Submit compete draft of thesis to advisor for comments
- **April 2, 2018**: Submit polished thesis to the committee
- **April 9, 2018**: Defend thesis